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Instrument Synthesis and Analysis Laboratory

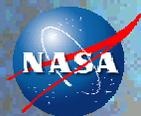
# Orbiting Wide-angle Light-collectors (OWL)

Optics

Dennis Evans

Scott Antonille

18 January 2002



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NASA GODDARD SPACE FLIGHT CENTER

# Optics Overview

Instrument Synthesis and Analysis Laboratory



- Goals Achieved and Concerns & Issues
- Successful Optical Point Design
- Packaging & Deployment
- Vignetting & Illumination
- Configuration History

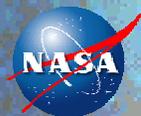




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Instrument Synthesis and Analysis Laboratory

# Goals Achieved and Concerns & Issues

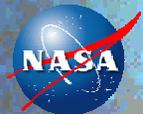


# Goals Achieved

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- **A Modified Schmidt Camera provides adequate image quality**
- **A 22.5 degree HFOV was achieved**
- **Vignetting by Focal Plane is tolerable**
- **Fabrication techniques are current state-of-the-art**

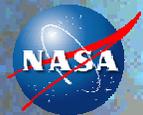


# Concerns & Issues

Instrument Synthesis and Analysis Laboratory



- **Dimensions**
  - Optical design in CM and MM
  - Mechanical design in MM and Inches
- **Primary Mirror**
  - Massive central vignetting
  - Might be able to redesign to be all petals, with no center section
  - Initial mass and cost estimate are for optical quality imaging, not precision microwave antenna. (Potential cost reduction)
- **Corrector**
  - Need to investigate plastics for mass, durability, & manufacturability



# Concerns & Issues

Instrument Synthesis and Analysis Laboratory

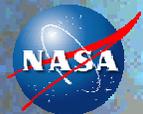


- **Support Structure Obscuration**

- Currently Strut Obscuration transmission factors from 0.75 to 0.88
- May be some “shadows” on detector with 0 transmission.
- Need to look at designs with lower obscuration.

- **Inflatable Structure**

- Helium gas and high voltage photomultipliers are compatibility hazards. He penetrates glass walls and makes them high voltage glow tubes.

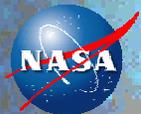


# Corrector & Filter Concerns

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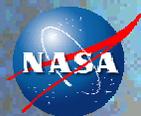
- **Single Lens**
  - Mechanical Analysis – domed advantage
  - Fabrication problem
- **Tiled Lens**
  - Mechanical Analysis– local domed advantage persists
  - One Spherical Surface
  - Diamond Turning?
- **UV Transmitting Plastics need to be investigated!**
  - Durability advantages
  - Weight advantages
  - Fabrication advantages – diamond turning
  - Acrylics and polycarbonates do transmit 0.280 micron UV





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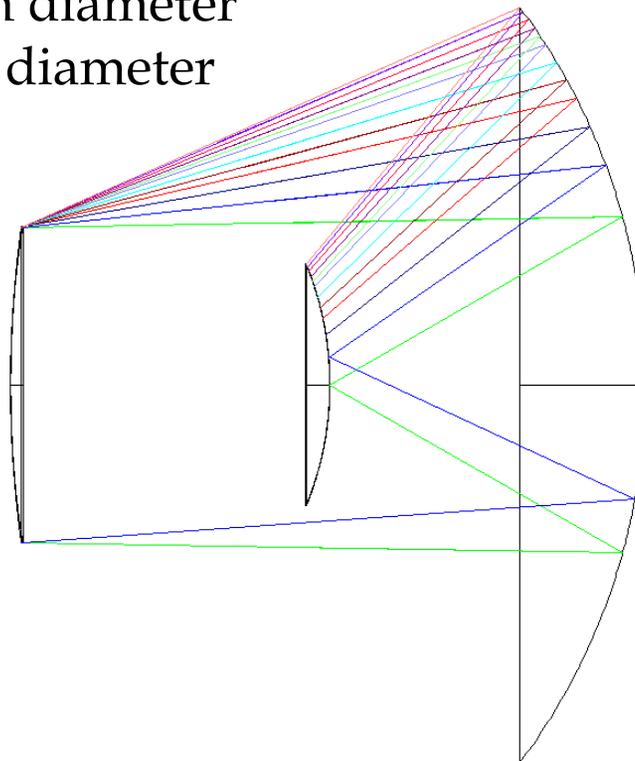
# Successful Optical Point Design



# F/1 Aspheric Schmidt

Instrument Synthesis and Analysis Laboratory

Aperture: 3.0 m diameter  
 Primary: 7.1 m diameter  
 HFOV = 22.5°



3D LAYOUT

SCHMIDT ASPHERIC F/1 HFOV 22.5 1/15/02 C F\_SILICA FILTER ON DETECTOR  
 THU JAN 17 2002

SCOTT ANTONILLE

GODDARD SPACE FLIGHT CENTER

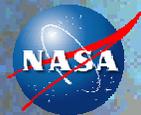
I:\ZEMAX\45FFOV F1 011502-C.ZMX  
 CONFIGURATION 1 OF 1

# Basic Schmidt Camera

Instrument Synthesis and Analysis Laboratory



- Entrance Stop Aperture – 3.000 meters diameter
- HFOV – 22.5 degrees
- Focal ratio –  $f/1$
- Focal length – 3 meters
- Primary mirror radius of curvature – 6 meters
- Focal plane radius of curvature – 3 meters
- Focal plane diameter – 2.3 meters
- Corrector – Fused Silica – Thin Dome – 10 cm chord relief
- PMT Filter (& window) – 3 mm thick on PMT.

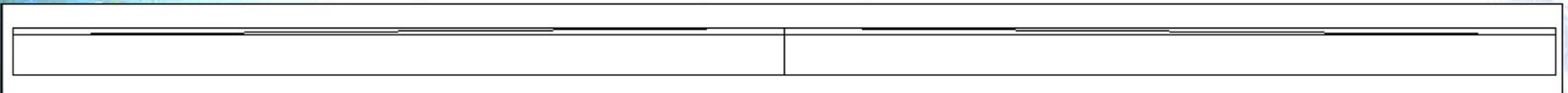


# Optimized Schmidt

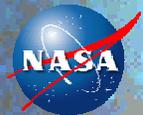
Instrument Synthesis and Analysis Laboratory



- **Corrector**
  - Front surface = sphere
  - Back surface = even aspheric
- **Primary**
  - even aspheric
- **Focal Surface**
  - Sphere
  - Could be optimized by tiling detectors



3 x 100 mm faceplate showing 3000 mm curvature

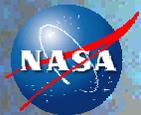


# Tolerance Summary



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- **Corrector:**
  - Corrector Mirror Dist: +/- 1cm
  - Tilt to axis: +/- 1 degree
  - Decenter: < | +/- 0.5cm
  - Fabrication: Segmented aspheric fabrication concerns
    - Radius: Low sensitivity (Corrector thickness is important)
- **Mirror**
  - Fab: (more like microwave antenna than imaging mirror)
    - $\frac{1}{4}$  to 1 wave in visible is more than sufficient quality.
  - Radius: = 2x delta thickness = +/- 0.2cm (refocus to correct fab error )
  - Thickness - Focal Plane Distance: +/- 0.1cm
  - Decenter: +/- 0.1cm
  - Tilt to axis & petals: +/- 0.02 degrees, 1.2 arcmin
    - Alignment scheme
- **Focal Plane**
  - Tilt to axis: +/- 0.1 degree



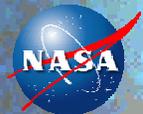
# Mass Estimate - Corrector

Instrument Synthesis and Analysis Laboratory



- **Corrector**

- Schmidt Corrector Mass-domed.dwg
- 3 meter aperture, 100 mm dome,
- Center thickness 3 mm, edge thickness 13 mm
- Fused Silica =  $2.2 \text{ gm.cm}^3$
- $56406 \text{ cm}^3 \times 2.2 \text{ gm.cm}^3 = 124095 \text{ grams} = \underline{124.1 \text{ kg}}$



# Mass Estimate - Primary Mirror

Instrument Synthesis and Analysis Laboratory

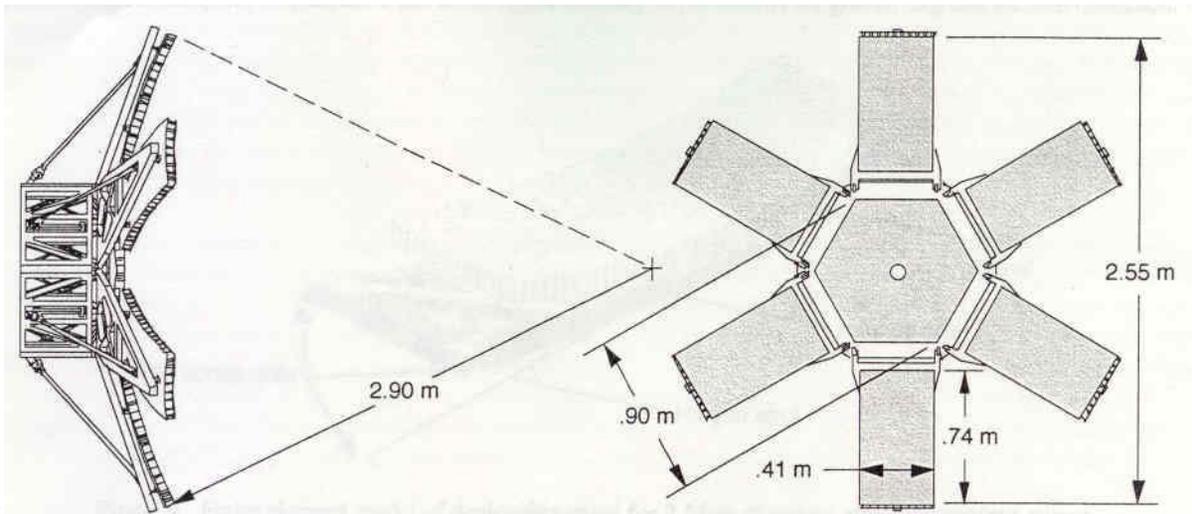


Figure 7. 2.55-m-diameter, proof-of-concept, deployable mirror.

$$.41 \times .74 = 0.3034 \text{ square meters}$$

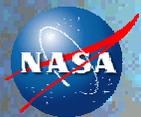
$$2.98 \text{ kg} \div 0.3034 \text{ m}^2 = 9.8 \text{ kg/m}^2$$

Area density of a quarter is about  $12 \text{ kg/m}^2$

$$\text{Area of Schmidt Primary} = 45.2 \text{ m}^2$$

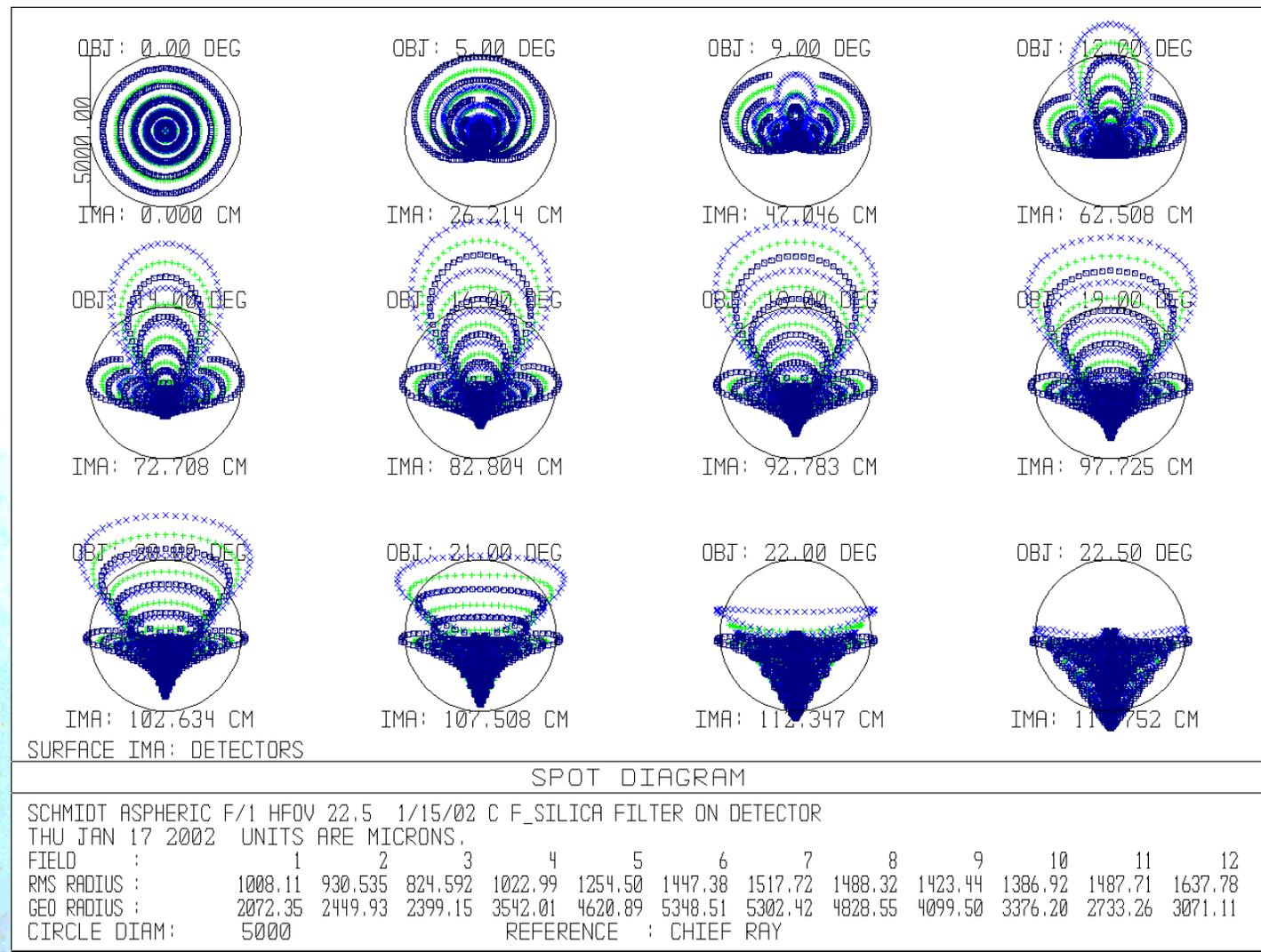
$$4.52 \text{ m}^2 \times 9.8 \text{ kg/m}^2 = 444.3 \text{ kg}$$

(SPIE Paper 3785-02 Mark Lake et al (1999) A Deployable Primary Mirror for Space Telescopes)



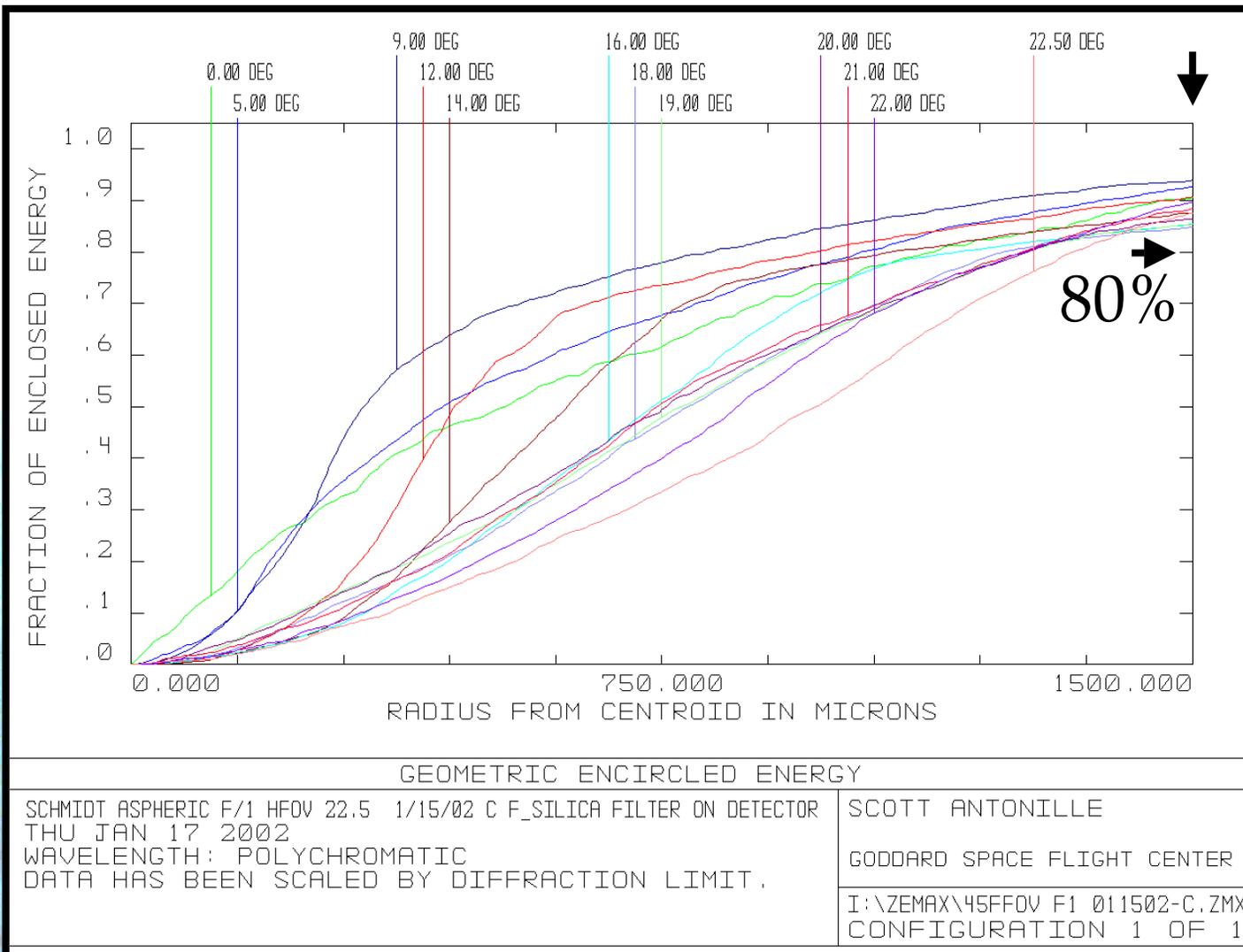
# Spot Diagrams

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# Encircled Energy

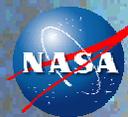
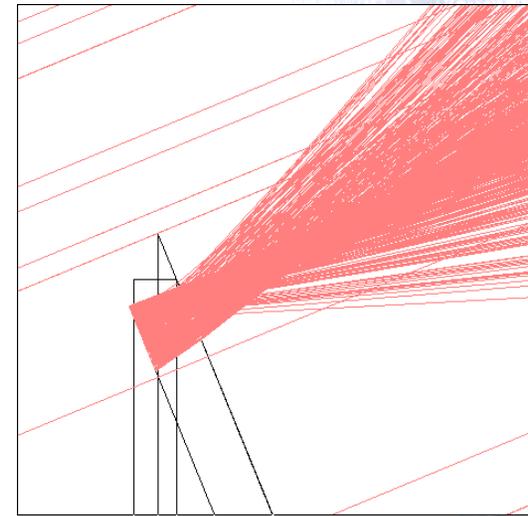
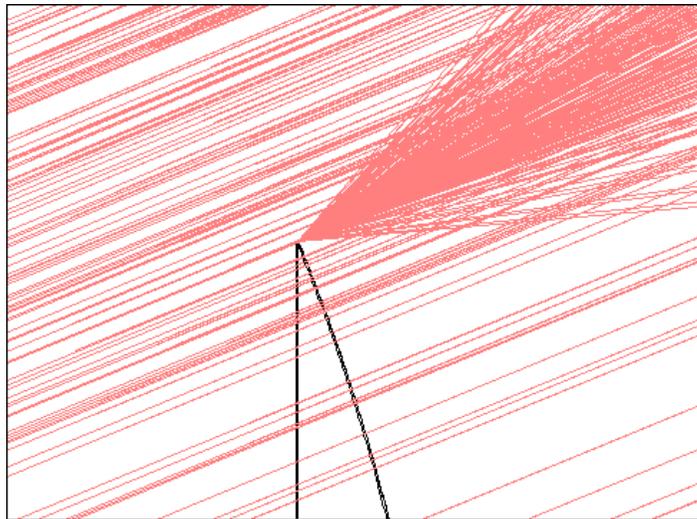
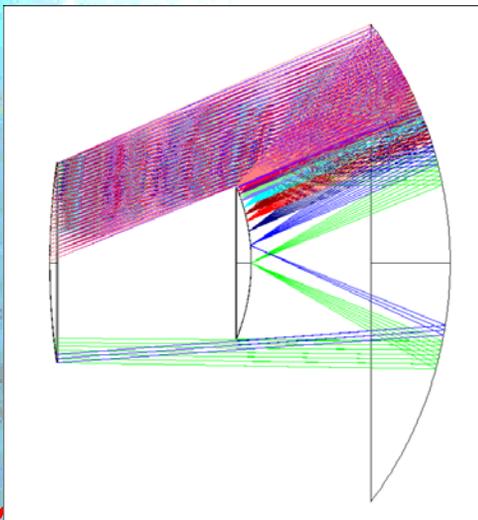
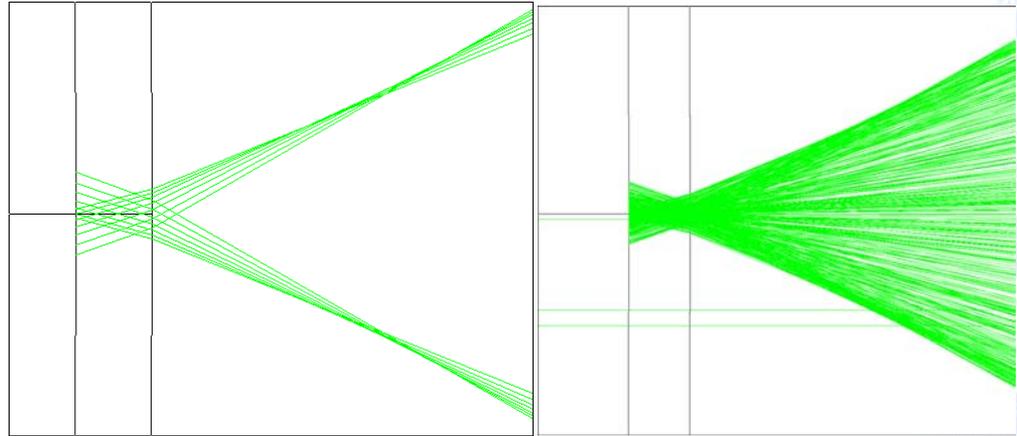
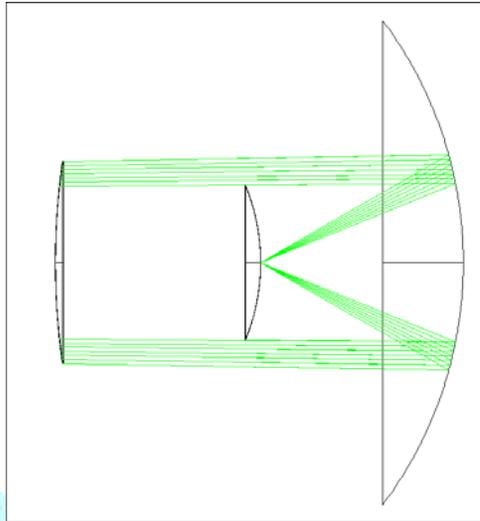
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# F/1 Light Cone at Detector



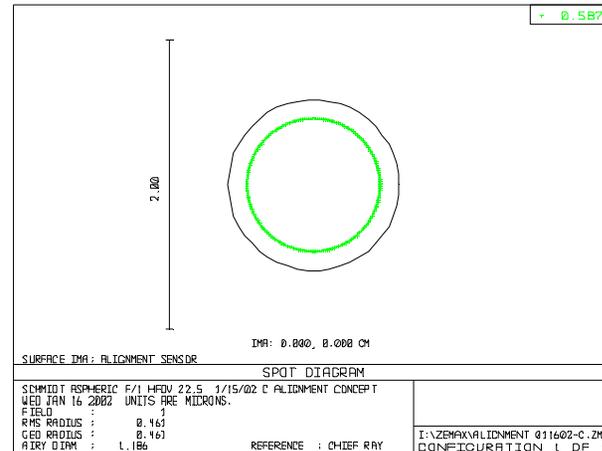
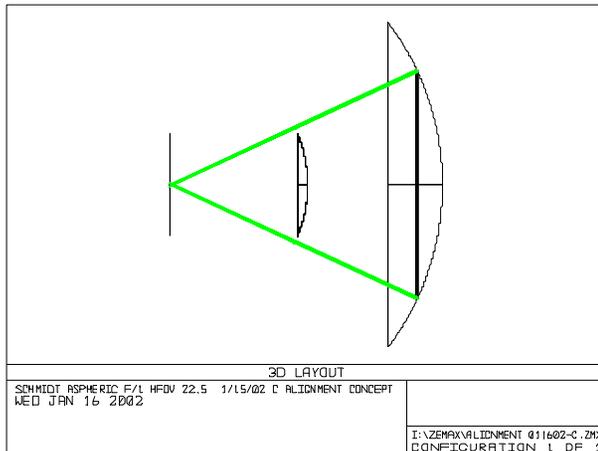
Instrument Synthesis and Analysis Laboratory



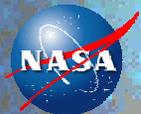
# Alignment Sensor



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- Install near Primary center of curvature in center vignetted position (at center of Corrector dome).
- Central region vignetting by Detector, just Petal testing.
- Illuminated outer zone & aspheric result in poor image
- Illuminated 5-cm wide ring on primary
- Return image is diffraction limited
- Need corrector-detector distance measurement.
- Concept is for ground testing and potentially flight alignment of the individual Primary Mirror petals.

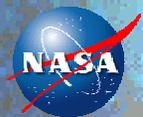


# Optimized Prescription



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#	Type	Comment	Curvature	Radius	Thickness	Glass	Semi Diameter	Conic	4nd Order	6th Order	8th Order	10th Order
0	STANDARD		0.00E+00		Infinite		0.0000	0				
1	STANDARD	CORRECTOR - FRONT	9.07E-04	1102.41	0.3000	F_SILICA	150.0000	0				
2	EVENASPH	CORRECTOR - BACK	9.10E-04	1098.99	603.5615		150.3598	0	2.1115E-09	2.2949E-14	-4.1764E-19	6.8172E-24
3	EVENASPH		-1.66E-03	-600.90	-299.8723		358.8210	0	2.8239E-12	-5.3089E-16	5.4902E-21	-2.4781E-26
4	STANDARD	OBSCURATION	-3.31E-03	-302.37	299.8723		114.7055	0	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
5	EVENASPH	PRIMARY	-1.66E-03	-600.90	-299.8723	MIRROR	358.8210	0	2.8239E-12	-5.3089E-16	5.4902E-21	-2.4781E-26
6	STANDARD	FILTER - WINDOW	-3.31E-03	-302.37	-0.3000	F_SILICA	114.8886	0				
7	STANDARD	DETECTORS	-3.30E-03	-302.67	0.0000		114.7133	0				





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Instrument Synthesis and Analysis Laboratory

# Packaging and Deployment

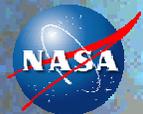


# Deployment

Instrument Synthesis and Analysis Laboratory



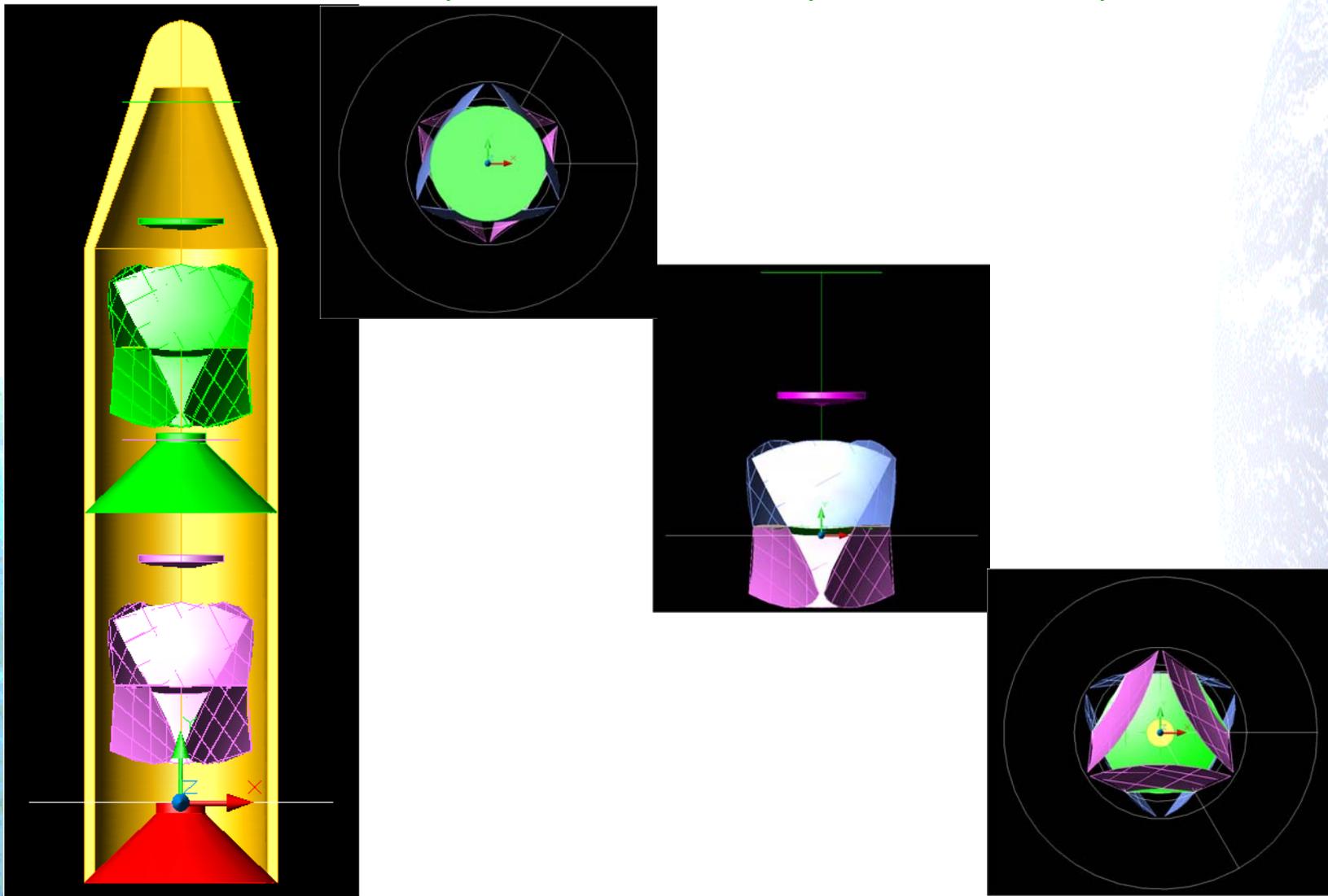
- Aperture requirements and Launch Costs require deployable telescope.
- Corrector must be deployed in all configurations considered.
- Monolithic and segmented primary mirrors are possible.



# Stowing the Instrument



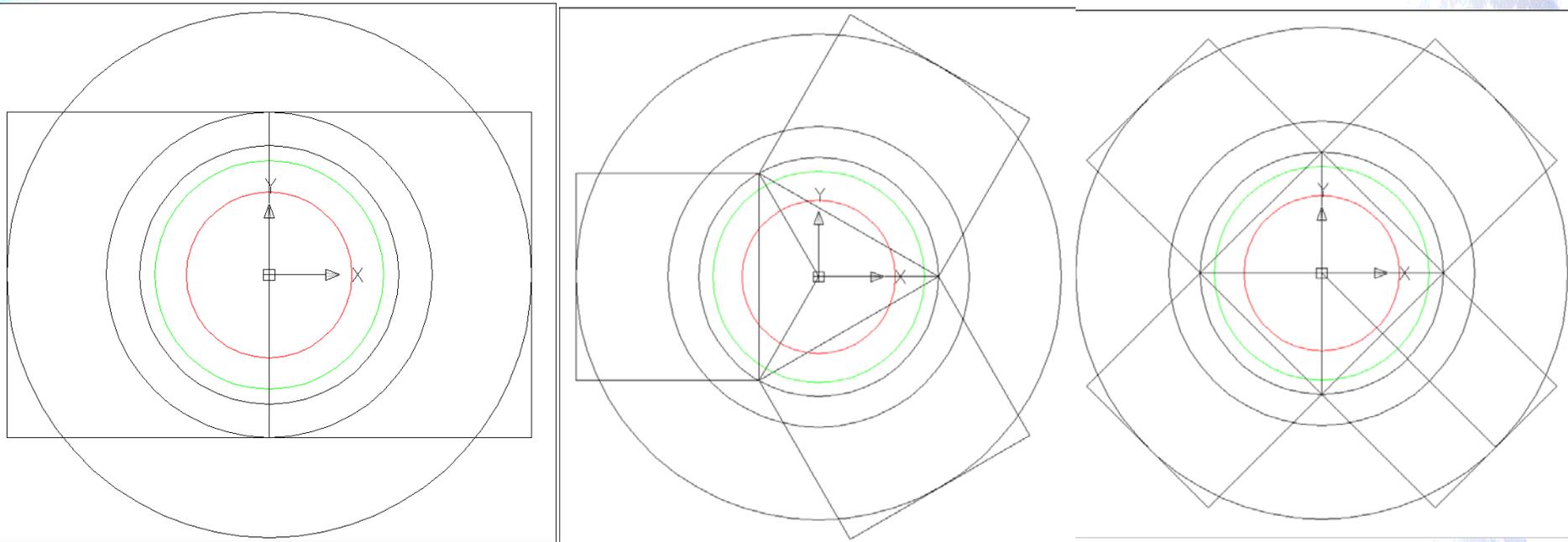
Instrument Synthesis and Analysis Laboratory



# Primary Mirror Folding

Instrument Synthesis and Analysis Laboratory

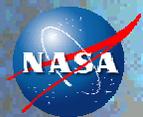
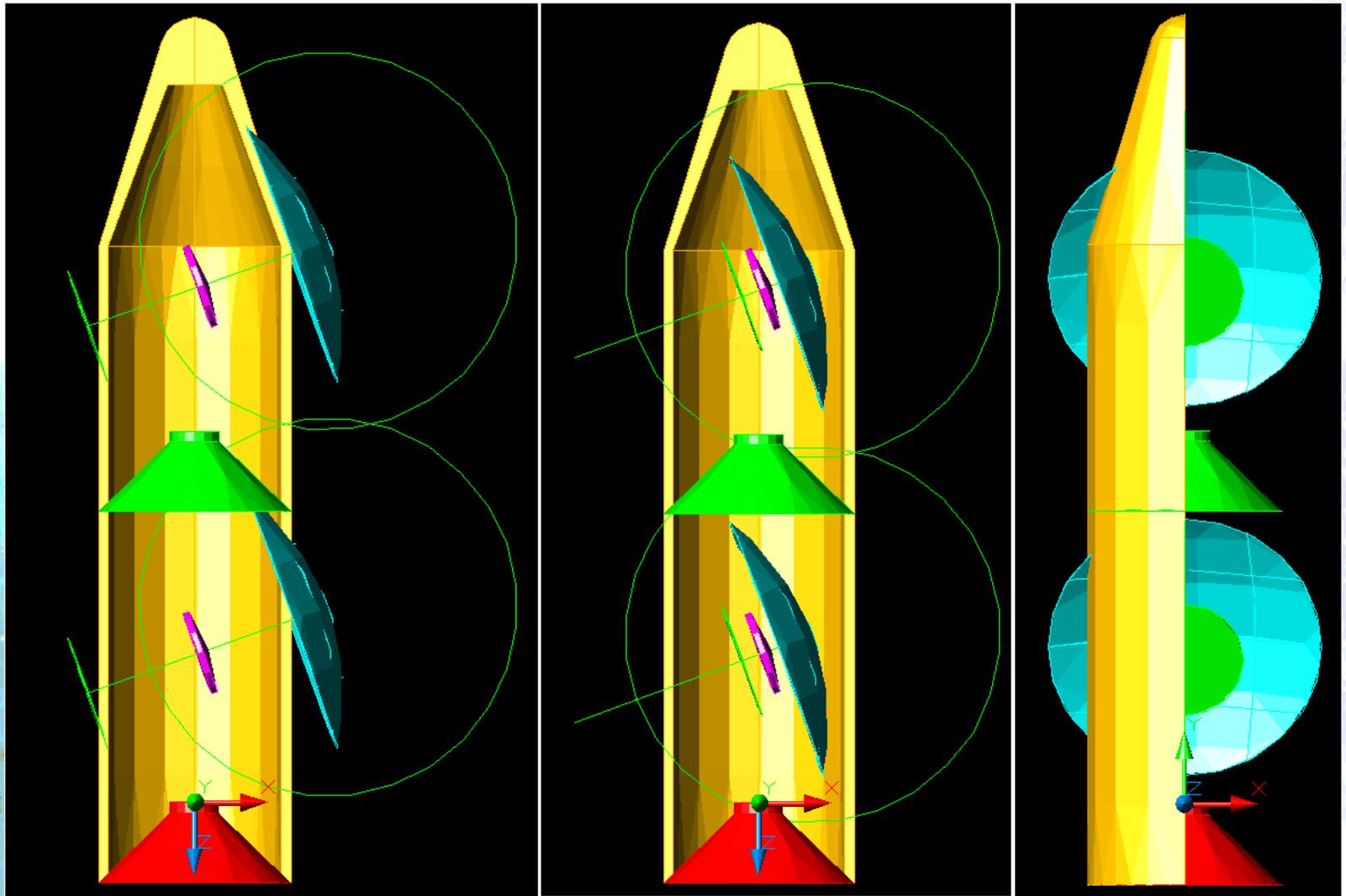
- Fold Forward only
- Simple Hinge
- Area Gaps
- Fewer Petals is better



# Alternate Packaging

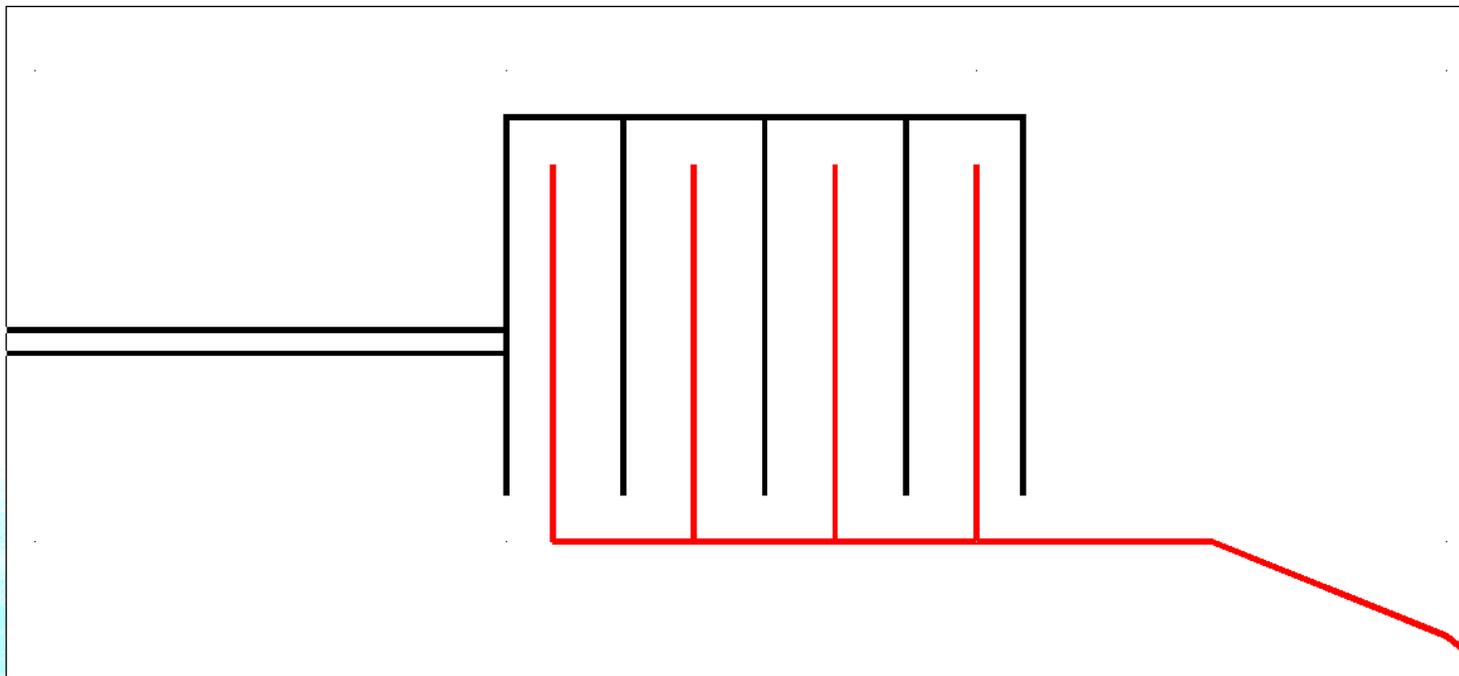


Instrument Synthesis and Analysis Laboratory



# Light Tight Cover

Instrument Synthesis and Analysis Laboratory



Attenuation needed  $-27\text{mv}$  to  $24\text{mv} = 51 \text{ mv}$

$(51 \div 5 = 10.2) \times 2 = 20.4$  numeric magnitudes

Surface Reflectivity = 0.05 to 0.15

Labyrinth channels = 8

Reflection per channel = 2, 3, 4 (narrower and longer is better)

$$0.05 * (8 \times 2) = 1.5E^{-21}$$

$$0.15 * (8 \times 2) = 6.6E^{-14}$$

$$0.05 * (8 \times 3) = 6.0E^{-32}$$

$$0.15 * (8 \times 3) = 1.7E^{-20}$$

$$0.05 * (8 \times 4) = 2.3E^{-42}$$

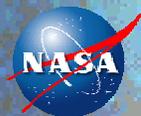
$$0.15 * (8 \times 4) = 4.3E^{-27}$$



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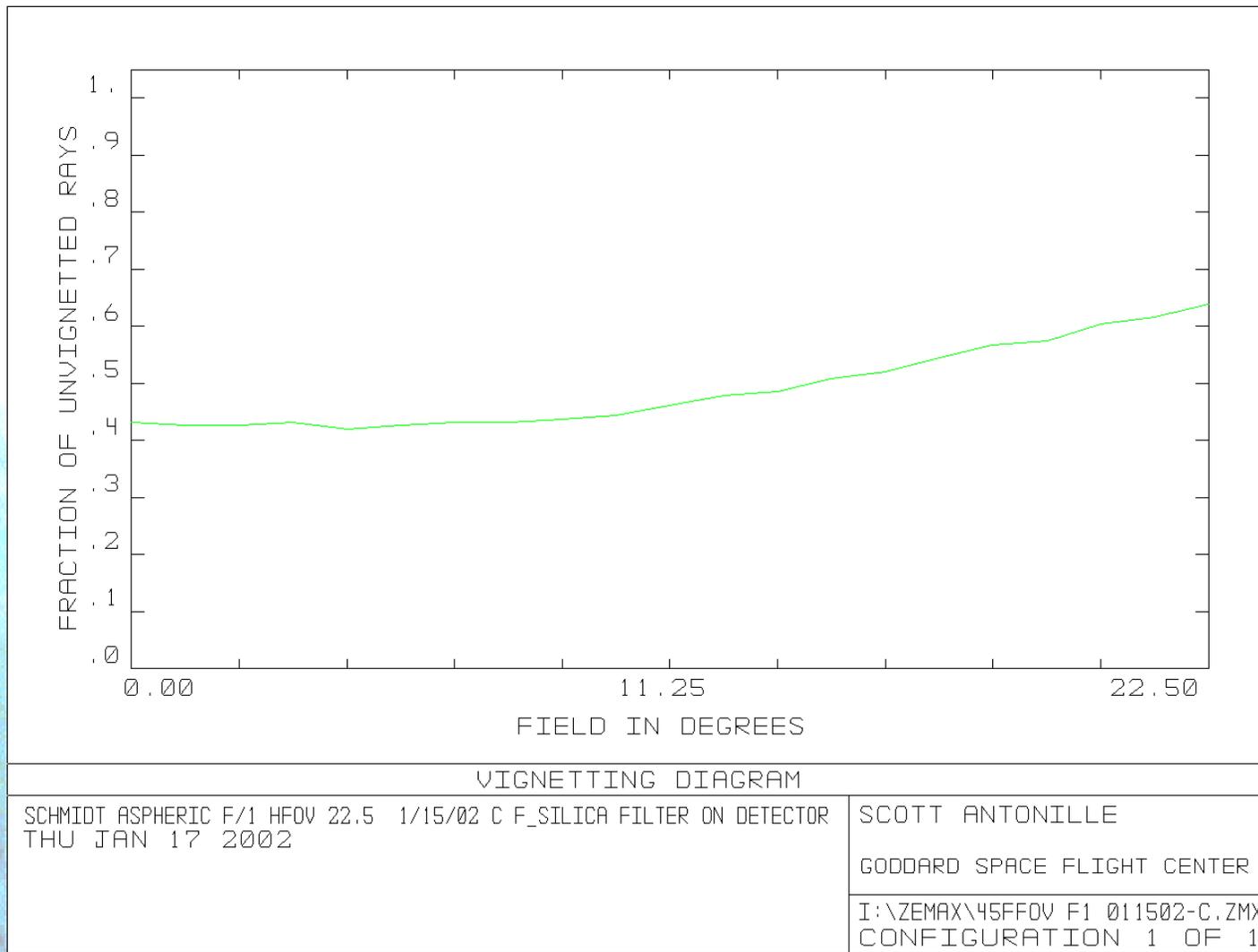
Instrument Synthesis and Analysis Laboratory

# Vignetting And Illumination



# Vignetting

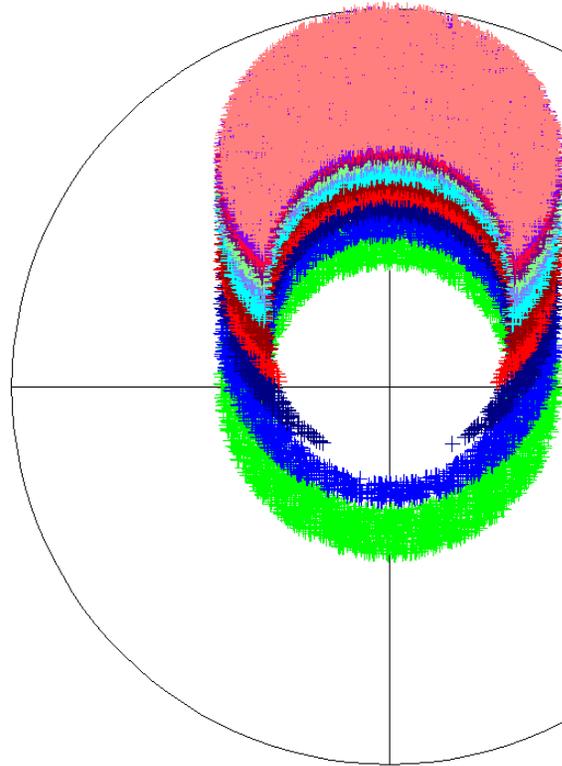
Instrument Synthesis and Analysis Laboratory



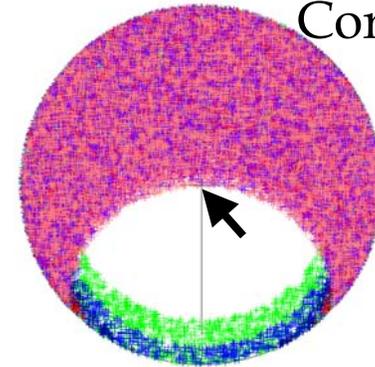
# Vignetting / Illumination

Instrument Synthesis and Analysis Laboratory

Primary



Corrector



3D LAYOUT	
SCHMIDT ASPHERIC F/1 HFOV 22.5 1/15/02 C F_SILICA FILTER ON DETECTOR THU JAN 17 2002	SCOTT ANTONILLE
	GODDARD SPACE FLIGHT CENTER
	I:\ZEMAX\45FF0V F1 011502-C.ZMX CONFIGURATION 1 OF 1

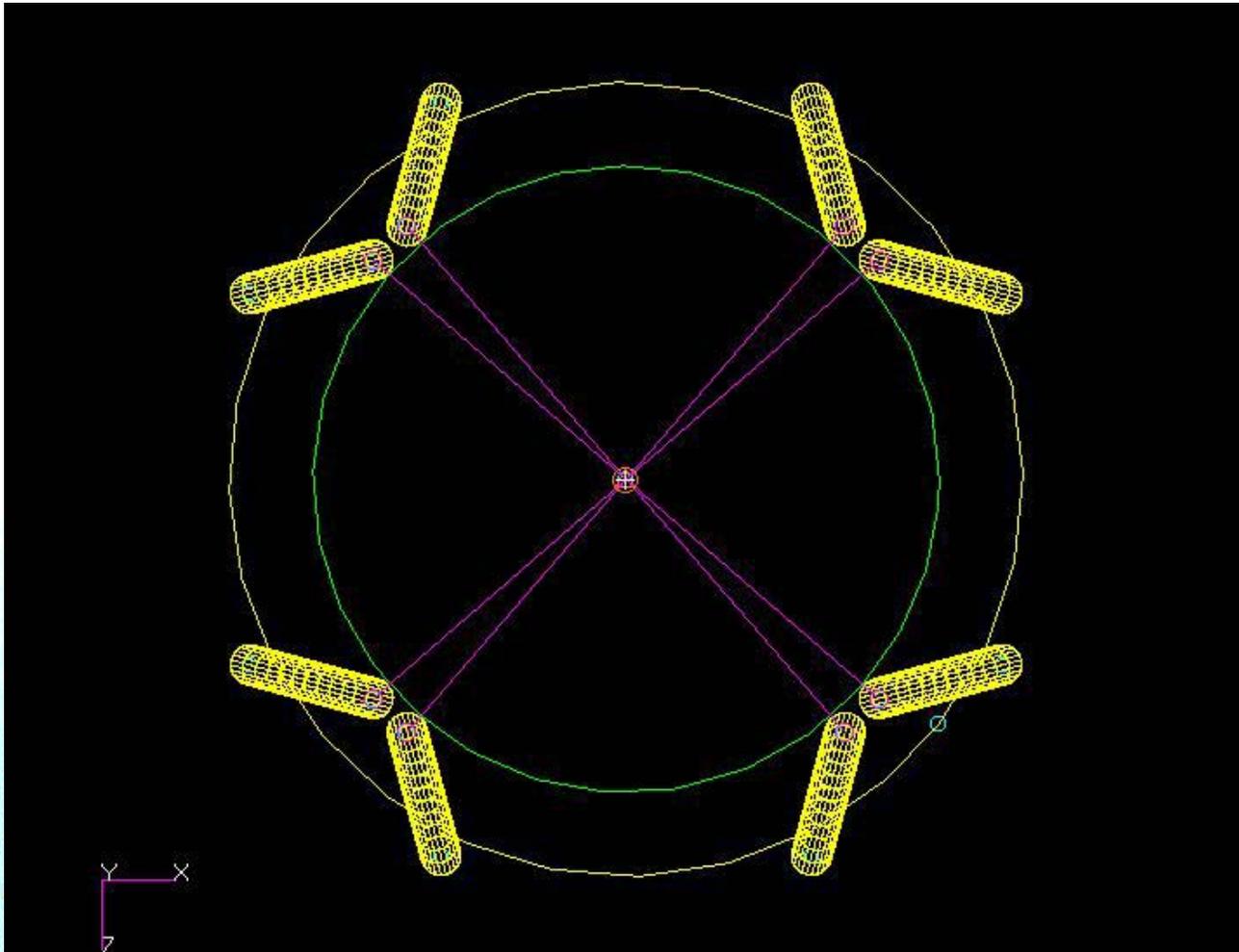
3D LAYOUT

SCHMIDT ASPHERIC F/1 HFOV 22.5 1/15/02 C F_SILICA FILTER ON DETECTOR THU JAN 17 2002	SCOTT ANTONILLE
VIGNETTING ON PRIMARY	GODDARD SPACE FLIGHT CENTER
	I:\ZEMAX\45FF0V F1 011502-C.ZMX CONFIGURATION 1 OF 1

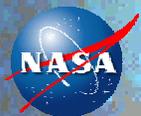
# Strut Transmission Fraction - On Axis



Instrument Synthesis and Analysis Laboratory



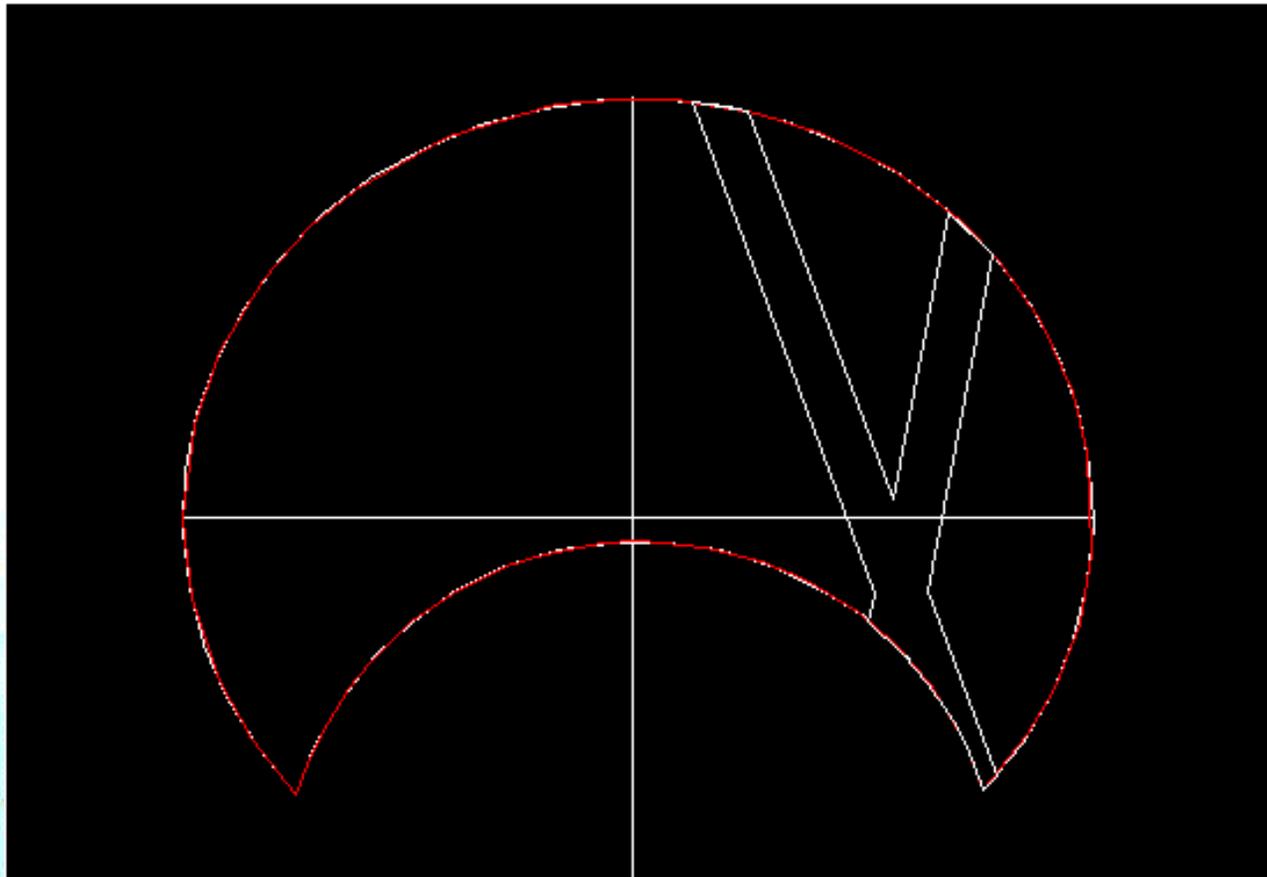
Octagonal = 0.77    Hexagonal = 0.83



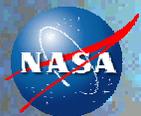
# Strut Transmission Fraction - Off Axis



Instrument Synthesis and Analysis Laboratory



Octagonal = 0.84 to 0.75    Hexagonal = 0.88 to 0.82

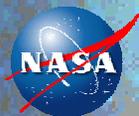




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Instrument Synthesis and Analysis Laboratory

# Configuration History

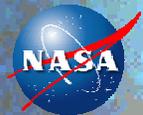


# Configuration History

Instrument Synthesis and Analysis Laboratory

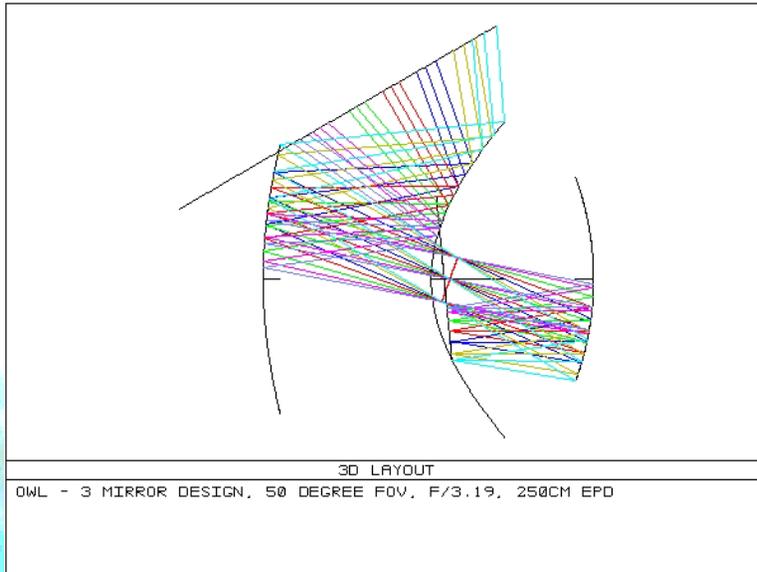


- **Double Fresnel-Maksutov (UAH)**
  - Two large curved complicated Fresnel surfaces plus a large mirror
  - Large Obscuration
- **Spherical Optics**
  - No corrector
  - Image quality too poor
- **Three Mirror Systems**
  - With a large field of view and low  $f/\#$ , mirrors become very large relative to stop, mirrors become complicated off-axis pieces
- **Simple Schmidt plate with Spherical Mirror**
  - Imaging too poor
- **Higher Order Schmidt plate with Spherical Mirror**
  - Image can be corrected over 19 deg HFOV at  $f/1.1$
- **Higher Order Schmidt Plate with Aspheric Mirror**
  - Image can be corrected over 22.5 deg HFOV at  $f/1$
  - Less obscuration lets aperture be cut, keeping mirror at  $\sim 7\text{m}$

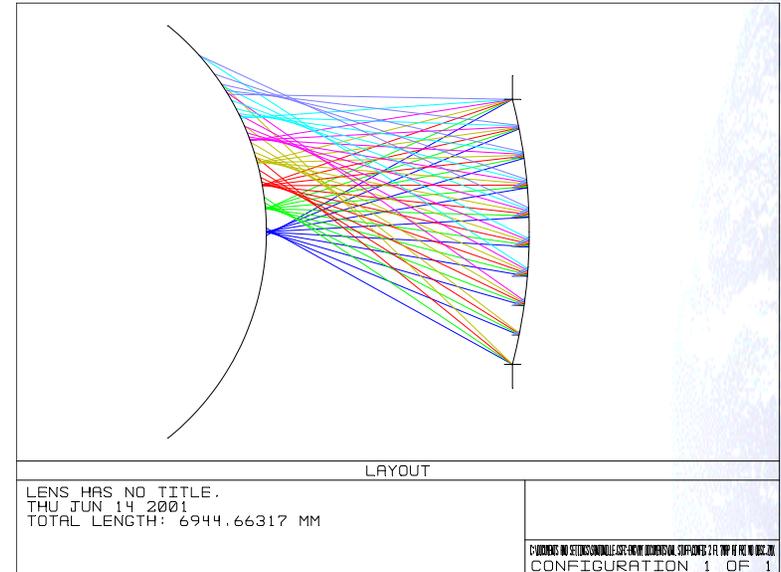


# Early Concept Layouts

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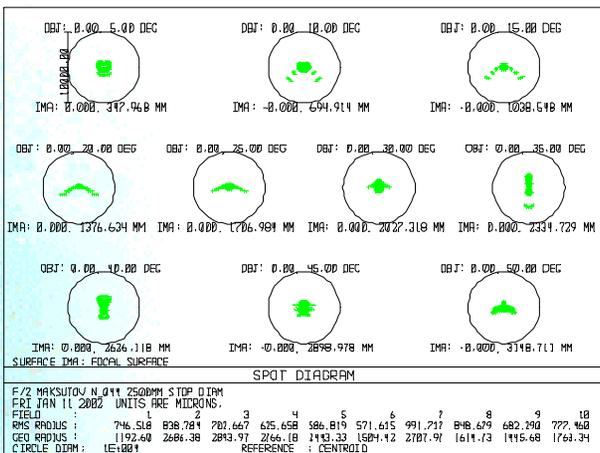
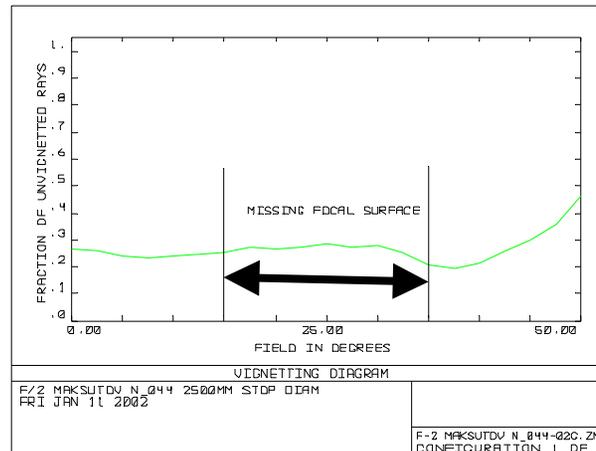
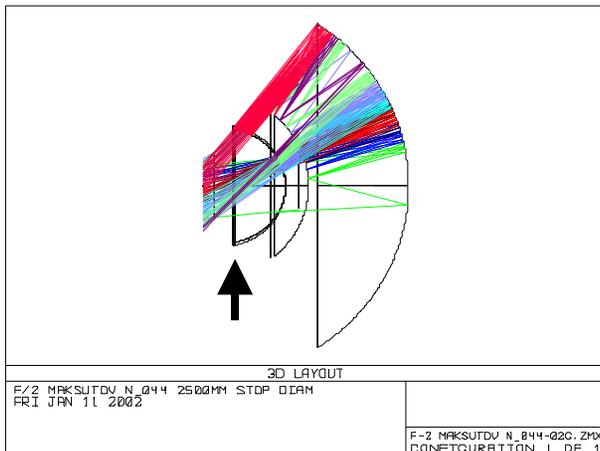
3 Mirror Reflective System  
 (adapted WAFFT)



Sphere

# ISAL Sample : F/2 Maksutov

Instrument Synthesis and Analysis Laboratory



Aperture: 3.0 m diameter  
 HFOV: 50°  
 Primary: 14.4 m diameter  
 Lens Mass: 1521 kg for 20° HFOV  
 Dual Ring Focal Surface

# Schmidt System Trades

alt	HFOV=15	Ground Area (km <sup>2</sup> )										Eft Apt m <sup>2</sup>
		17.5	20	22.5	25	27.5	30	32.5	35	37.5	40	
400	36,089	49,971	66,589	86,242	109,299	136,214	167,552	204,007	246,447	295,958	353,913	0.48
450	45,675	63,244	84,277	109,150	138,331	172,396	212,058	258,196	311,909	374,572	447,922	0.61
500	56,389	78,079	104,045	134,753	170,779	212,835	261,799	318,761	385,073	462,435	552,990	0.75
550	68,231	94,476	125,895	163,051	206,643	257,530	316,777	385,700	465,939	559,547	669,117	0.91
600	81,200	112,434	149,825	194,044	245,922	306,483	376,991	459,015	554,506	665,907	796,305	1.08
650	95,297	131,954	175,836	227,733	288,617	359,691	442,441	538,705	650,774	781,515	934,552	1.27
700	110,523	153,035	203,928	264,116	334,727	417,157	513,127	624,771	754,744	906,373	1,083,860	1.47
750	126,875	175,678	234,101	303,194	384,253	478,879	589,049	717,211	866,415	1,040,479	1,244,227	1.69
800	144,356	199,882	266,355	344,968	437,195	544,858	670,206	816,027	985,788	1,183,834	1,415,653	1.92
850	162,964	225,648	300,690	389,436	493,552	615,093	756,600	921,218	1,112,862	1,336,438	1,598,140	2.17
900	182,701	252,976	337,106	436,600	553,325	689,586	848,230	1,032,784	1,247,638	1,498,290	1,791,686	2.43
950	203,564	281,865	375,603	486,458	616,513	768,335	945,096	1,150,726	1,390,115	1,669,391	1,996,292	2.71
1000	225,556	312,316	416,180	539,012	683,117	851,340	1,047,198	1,275,042	1,540,293	1,849,741	2,211,958	3.00
	max area at f/#	f/1.2	f/1.1	f/1.0	f/0.9			f/0.8				
	aperture (m)	3.42	3.62	3.66	3.51			3.83				
	mirror size (m)	6	6.4	6.4	6.04			6.53				
	pixel size (mm)	4.1	4	3.66	3.16			3.06				
	eff theo	0.33	0.29	0.29	0.31			0.26				
	eff act	0.32	0.29	0.28								
	ext ensq % at pix	70-73	58-60	26-50								
	mirror act D (m)	8.6	9	9								
	pt ensq % at pix	~87-99	70-95	45-93								

f/# systems are completely obscured or optics excessively large to right of colored lines

+ eff ←

# Goals Achieved

Instrument Synthesis and Analysis Laboratory



- **A Modified Schmidt Camera provides adequate image quality**
- **A 22.5 degree HFOV was achieved**
- **Vignetting by Focal Plane is tolerable**
- **Fabrication techniques are current state-of-the-art**

